PB80-198369

Exhaust Emissions from a Diesel-Powered Volkswagen Rabbit

(U.S.) Environmental Protection Agency
Ann Arbor, MI

Oct 75

U.S. Department of Commerce
National Technical Information Service
NTIS

EPA-AA-TAEB 76-06

PB80-198369

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Technology Assessment and Evaluation Branch
Emission Control Technology Division
Office of Mobile Source Air Pollution Control
Environmental Protection Agency

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA 22161

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO.	2.	3. RECIPIENT'S ACCESSION NO.
EPA-AA-TAEB-76-06		

4. TITLE AND SUBTITLE	5. REPORT DATE
Exhaust Emissions from a Diesel-Powered Volkswagen Rabbit	October 1975
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S)	8. PERFORMING ORGANIZATION REPORT NO.
No author given	
9. PERFORMING ORGANIZATION NAME AND ADDRESS U.S. Environmental Protection Agency Office of Mobile Source Air Pollution Control Technology Assessment & Evaluation Branch Ann Arbor, Michigan 48105	10. PROGRAM ELEMENT NO.
	11. CONTRACT/GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS SAME AS BOX 9	13. TYPE OF REPORT AND PERIOD COVERED Technical
	14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

16. ABSTRACT

The Emission Control Technology Division of the U.S. Environmental Protection Agency is responsible for keeping abreast of new developments in automotive emission control. This responsibility includes testing of prototype vehicles that incorporate new developments in control technology and power systems.

Volkswagenwerk A.G. has developed a small Diesel engine for installation in the VW Rabbit. This engine potentially offers low exhaust emissions and high fuel economy. A prototype Diesel-powered Rabbit was made available to the EPA for an evaluation of its emission and fuel economy performance.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Diesel engines Automobiles Exhaust emissions Fuel consumption Tests	Volkswagen Rabbit Fuel economy	

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS *(This Report)*	21. NO. OF PAGES
Release unlimited	Unclassified	14 p.
	20. SECURITY CLASS *(This page)*	22. PRICE
	Unclassified	

EPA Form 2220-1 (9-73)

Background

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Volkswagenwerk A.G. has developed a small Diesel engine for installation in the VW Rabbit. This engine potentially offers low exhaust emissions and high fuel economy. A prototype Diesel-powered Rabbit was made available to the EPA for an evaluation of its emission and fuel economy performance.

Test Vehicle Description

The prototype Diesel engine is installed in a 1975 Volkswagen Rabbit sedan. The engine is a 4-stroke, overhead cam design, with a displacement of 1500 cc. Rather than designing a new engine, VW has Dieselized an existing 1500 cc gasoline engine. The Diesel engine is built on a block which is almost identical to the 1500 cc gasoline block. According to VW, the only modification made to the gasoline block is a small change in a coolant passageway. The same main bearings are used for both the Diesel and gasoline engines.

The cylinder head has been redesigned to accomodate a prechamber. The combustion chamber is a modified Ricardo Comet Mark V type. An external toothed belt drives both the camshaft and the fuel pump. Glowplugs are used as a starting aid, and are operated by the ignition key.

The Diesel engine weighs 6 lbs. more than the 1500 cc gasoline engine. The total weight of the Diesel Rabbit is 34 lbs. more than the weight of the gasoline Rabbit. This is due to modifications necessary for installation of the Diesel engine (larger battery, etc.).

The power output of the Diesel engine is approximately the same as that of an 1100 cc gasoline engine which is produced by VW for the European market. The performance of the Diesel Rabbit is comparable to that of the 1100 cc Rabbit.

Engine and vehicle statistics can be found in the vehicle description sheet in the appendix.

Figure 1: Volkswagen Rabbit Sedan.

Test Program

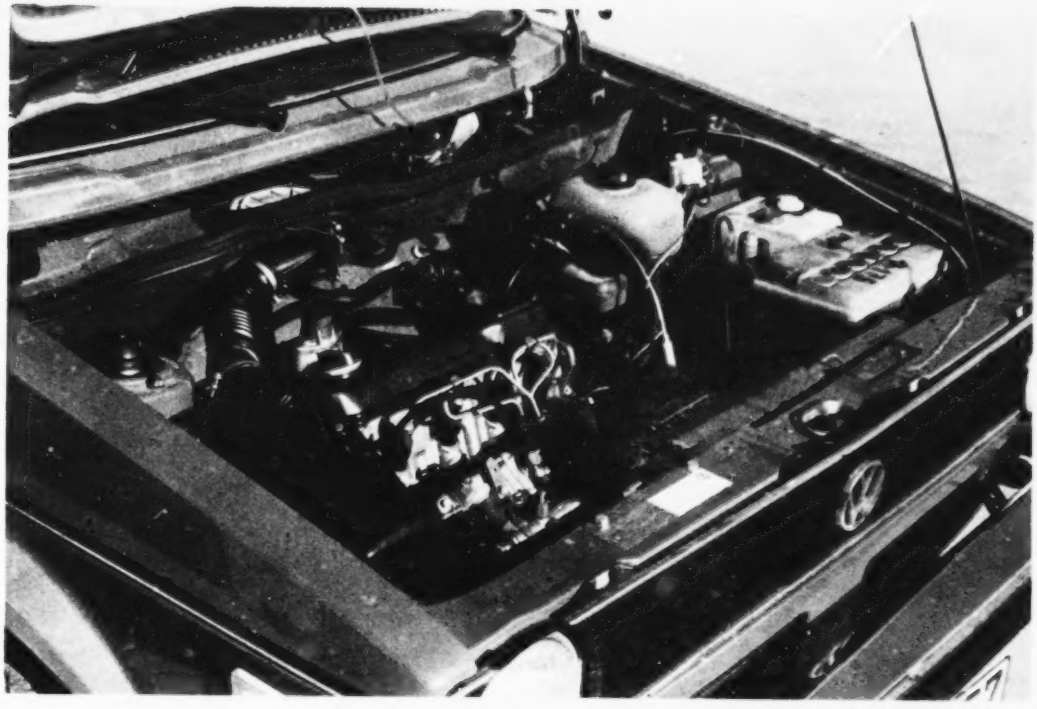
Exhaust emissions and fuel economy were measured in accordance with the 1975 Federal Test Procedure ('75 FTP) for light-duty Diesel-powered vehicles and the EPA Highway Driving Cycle. Sulfate emissions were measured over the EPA Sulfate Cycle. The fuel used for the sulfate testing was #2 Diesel fuel containing 0.21 wt. % sulfur. A description of the procedure used for measuring sulfate emissions is given in the appendix.

When the test vehicle was delivered to the EPA laboratory, it had accumulated 2500 miles. Four emissions tests were run on the vehicle, two using the tank fuel and two using #2 Diesel fuel. The tank fuel was a European Diesel fuel that was in the vehicle when it was delivered. Due to an instrument malfunction, hydrocarbon emissions were not measured during these initial tests.

After the first four tests were completed, the Rabbit was returned to VW for several weeks. When the vehicle returned to the EPA, it had accumulated another 2000 miles.

Four more emission and fuel economy tests were run. Two tests were run on #2 Diesel fuel and two on #1 Diesel fuel.

In addition, 0-60 mph acceleration time was measured.



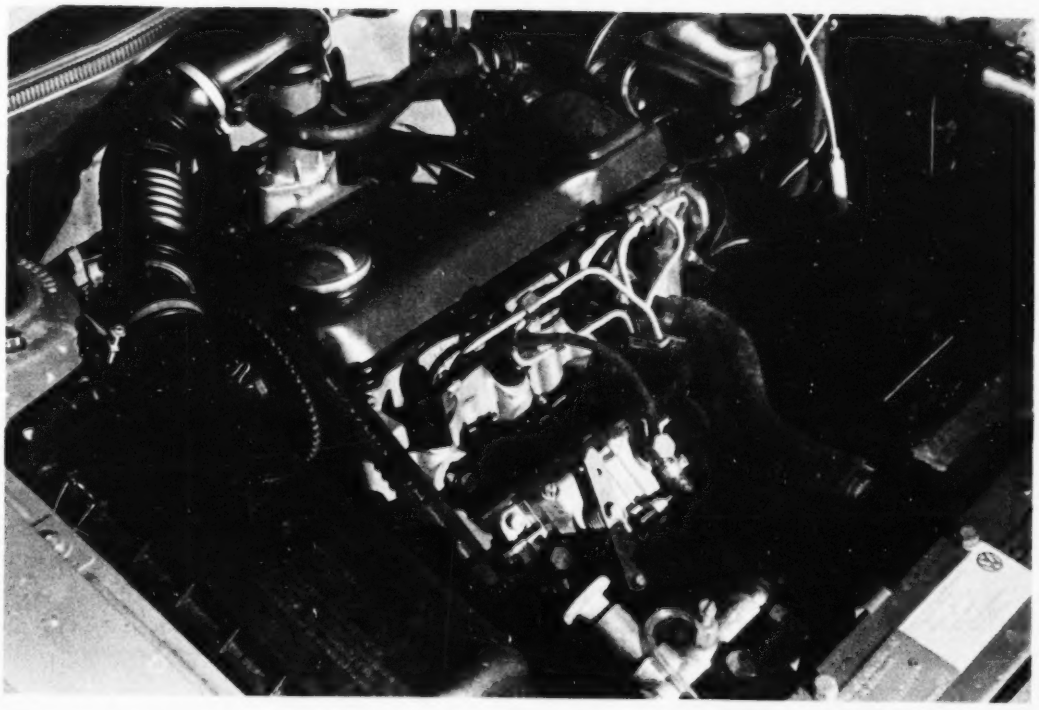


Figure 2: Close-up of the engine installation. Note the belt drive for the fuel pump and camshaft.

Test Results

The Diesel-powered Rabbit demonstrated the following exhaust emission levels:

'75 FTP Composite Mass Emissions
grams per mile
(grams per kilometer)

	HC	CO	NOx	Fuel Economy (Fuel Consumption)
#2 Diesel Fuel avg. of 4 tests	0.19 (0.12)	0.98 (0.61)	1.19 (0.74)	37.2 mpg (6.3 liters/100 km)
#1 Diesel Fuel avg. of 2 tests	0.11 (0.06)	0.74 (0.46)	1.12 (0.70)	36.3 mpg (6.5 liters/100 km)
VW type 2D Fuel avg. of 2 tests		0.69 (0.43)	1.19 (0.74)	39.4 mpg (6.0 liters/100 km)

Emissions and fuel economy measured over the EPA Highway Driving Cycle are presented in the following table:

EPA Highway Cycle
grams per mile
(grams per kilometer)

	HC	CO	NOx	Fuel Economy (Fuel Consumption)
#2 Diesel Fuel avg. of 4 tests	0.07 (0.05)	0.46 (0.29)	0.96 (0.60)	48.2 mpg (4.9 liters/100 km)
#1 Diesel Fuel avg. of 2 tests	0.05 (0.03)	0.47 (0.29)	0.88 (0.55)	48.4 mpg (4.9 liters/100 km)
VW type 2D Fuel avg. of 2 tests		0.38 (0.24)	0.97 (0.60)	50.3 mpg (4.7 liters/100 km)

If the harmonic mean of the '75 FTP (urban) and highway fuel economies is calculated using weighting factors of 55% for the urban cycle and 45% for the highway cycle, then the combined fuel economy is:

#2 Diesel Fuel: 41.5 mpg (5.7 ℓ/100 km)
#1 Diesel Fuel: 40.9 mpg (5.8 ℓ/100 km)
VW type 2D Fuel: 43.7 mpg (5.4 ℓ/100 km)

The 55/45 weighting factors have been determined to be typical of passenger car operation in the U.S. by the Department of Transportation.

A factor contributing to the higher fuel economy when using the VW fuel may be that the injection timing is optimized for the VW fuel.

Sulfate emissions measured over the EPA sulfate cycle are presented in Table V. Emissions of SO_4 are in milligrams per mile. The percent of fuel sulfur that is converted to SO_4 is also shown in Table V.

Based on an average of two runs, the acceleration time from 0-60 mph is 16.5 seconds.

Conclusions

The exhaust emissions from the Diesel Rabbit are well below the emission standards for the 1977 model year. HC and CO emissions are within the standards for the 1978 model year, but NOx emissions are about three times the 0.4 gm/mi level required for 1978.

The fuel economy of the Diesel Rabbit is considerably better than any other vehicle in its weight class. The combined urban/highway fuel economy is 26% higher than the best fuel economy achieved in the 2250 lb. inertia weight class during 1976 certification of light-duty vehicles, and is 52% higher than the average combined fuel economy for the 2250 lb. weight class.

The 0-60 mph acceleration time of 16.5 seconds is quicker than any other Diesel-powered car tested by the EPA. EPA engineering personnel who drove the car judged its driveability and performance to be fully adequate for all normal driving situations.

Table I

1975 Federal Test Procedure
Mass Emissions in
Grams per Mile
(Grams per Kilometer)

2500 mi./4000 km

Test #	HC	CO	CO_2	NOx	75 FTP mpg(l/100 km)	Highway mpg(l/100 km)
Volkswagen Fuel						
16-1631		0.70 (0.44)	259. (161.)	1.22 (0.76)	39.1 (6.0)	50.8 (4.6)
16-1649		0.68 (0.42)	255. (158.)	1.15 (0.71)	39.7 (5.9)	49.7 (4.7)
Average		0.69 (0.43)	257. (160.)	1.19 (0.74)	39.4 (6.0)	50.3 (4.7)
EPA #2 Diesel Fuel						
16-1897		0.95 (0.59)	272. (169.)	1.18 (0.73)	37.2 (6.3)	48.7 (4.8)
15-1898		1.04 (0.65)	260. (162.)	1.15 (0.71)	38.9 (6.0)	48.8 (4.8)
Average		1.00 (0.62)	266. (166.)	1.17 (0.72)	38.1 (6.2)	48.8 (4.8)

4500 mi./7200 km

EPA #2 Diesel Fuel						
16-1955	0.18 (0.11)	0.90 (0.56)	282. (175.)	1.22 (0.76)	35.9 (6.6)	46.5 (5.1)
15-1956	0.20 (0.12)	1.02 (0.63)	275. (171.)	1.22 (0.76)	36.7 (6.4)	48.7 (4.8)
Average	0.19 (0.12)	0.96 (0.60)	279. (173.)	1.22 (0.76)	36.3 (6.5)	47.6 (5.0)
EPA #1 Diesel Fuel						
16-2265	0.12 (0.07)	0.74 (0.46)	268. (167.)	1.09 (0.68)	36.0 (6.5)	48.3 (4.9)
15-2264	0.10 (0.06)	0.73 (0.45)	277. (172.)	1.14 (0.71)	36.6 (6.4)	48.4 (4.9)
Average	0.11 (0.06)	0.74 (0.46)	273. (170.)	1.12 (0.70)	36.3 (6.5)	48.4 (4.9)

Table II

EPA Highway Cycle
Mass Emissions in
Grams per Mile
(Grams per Kilometer)

2500 mi./4000 km

Test #	HC	CO	CO_2	NOx	mpg(1/100 km)
Volkswagen Fuel					
16-1631		0.39 (0.24)	200. (124.)	0.97 (0.60)	50.8 (4.6)
16-1649		0.37 (0.23)	204. (127.)	0.97 (0.60)	49.7 (4.7)
Average		0.38 (0.24)	202. (126.)	0.97 (0.60)	50.3 (4.7)
EPA #2 Diesel Fuel					
16-1897		0.50 (0.31)	208. (129.)	0.91 (0.57)	48.7 (4.8)
15-1898		0.50 (0.31)	208. (129.)	0.95 (0.59)	48.8 (4.8)
Average		0.50 (0.31)	208. (129.)	0.93 (0.58)	48.8 (4.8)

4500 mi./7200 km

EPA #2 Diesel Fuel					
16-1955	0.06 (0.04)	0.41 (0.25)	218. (135.)	1.04 (0.65)	46.5 (5.1)
15-1956	0.08 (0.05)	0.43 (0.27)	208. (129.)	0.95 (0.59)	48.7 (4.8)
Average	0.07 (0.05)	0.42 (0.26)	213. (132.)	1.00 (0.62)	47.6 (5.0)
EPA #1 Diesel Fuel					
16-2265		0.45 (0.28)	210. (131.)	0.85 (0.53)	48.3 (4.9)
15-2264	0.05 (0.03)	0.48 (0.30)	209. (130.)	0.90 (0.56)	48.4 (4.9)
Average	0.05 (0.03)	0.47 (0.29)	210. (131.)	0.88 (0.55)	48.4 (4.9)

Table III

Steady State Mass Emissions in
Grams per Mile
(Grams per Kilometer)

EPA #2 Diesel Fuel

Test #		HC	CO	CO_2	NOx	mpg(1/100 km)
Idle						
15-1644			1.76 gms	106. gms	0.54 gms	
15 mph/24 kph	2nd gear					
15-1645			1.67 (1.04)	221. (137.)	0.80 (0.50)	45.4 (5.2)
30 mph/48 kph	4th gear					
15-1646			0.51 (0.32)	154. (96.)	0.66 (0.41)	65.7 (3.6)
45 mph/72 kph	4th gear					
15-1647			0.43 (0.27)	180. (112.)	0.95 (0.59)	56.0 (4.2)
60 mph/97 kph	4th gear					
15-1648			0.50 (0.31)	214. (133.)	0.97 (0.60)	47.3 (5.0)

Table IV

VW Rabbit Diesel
Individual Bag Emissions in
Grams per Mile

	Bag 1: Cold Transient					Bag 2: Stabilized					Bag 3: Hot Transient					
Test #	HC	CO	CO_2	NOx	mpg	HC	CO	CO_2	NOx	mpg	HC	CO	CO_2	NOx	mpg	Weighted 75 mpg
							2500 Miles									
Volkswagen Fuel																
16-1631		0.75	293.	1.16			0.77	252.	1.29			0.53	246.	1.13		
16-1649		0.73	277.	1.16			0.73	256.	1.19			0.55	238.	1.07		
EPA #2 Diesel Fuel																
16-1897		0.89	269.	1.10	37.6		1.14	299.	1.35	33.8		0.69	230.	0.98	44.0	37.2
15-1898		1.04	286.	1.18	35.3		1.20	257.	1.17	39.2		0.73	246.	1.08	41.1	38.9
							4500 Miles									
EPA #2 Diesel Fuel																
16-1955	0.93	1.00	303.	1.24	33.3	0.72	0.97	285.	1.26	35.5	0.44	0.70	260.	1.14	39.0	35.9
15-1956	1.27	1.10	299.	1.23	33.8	0.66	1.14	273.	1.25	36.9	0.48	0.74	259.	1.14	39.1	36.7
EPA #1 Diesel Fuel																
16-2265	0.73	0.77	280.	1.08	34.5	0.39	0.79	273.	1.15	35.4	0.33	0.62	250.	0.98	38.7	36.0
15-2264	0.47	0.83	305.	1.18	33.2	0.37	0.75	273.	1.16	37.1	0.31	0.61	263.	1.07	38.5	36.6

Table V

EPA Sulfate Cycle
Mass Emissions and
Fuel Economy

Gaseous Emissions grams per mile		Fuel Economy mpg	Sulfates Emissions milligrams per mile	% Conversion of S to SO_4
CO	NOx			
0.58	1.02	46.5	10.12	2.60
0.58	0.99	45.7	9.19	2.32
0.56	0.98	46.2	10.29	2.63
0.58	1.00	44.0	10.84	2.64
0.56	1.03	46.9	9.31	2.41
0.58	1.04	45.3	8.68	2.17
0.59	0.96	47.0	8.39	2.18
0.58	0.96	46.2	8.49	2.17

Appendix

VW Diesel Rabbit
Procedure used to Measure Sulfate Emissions

1. The fuel was drained from the test vehicle. The vehicle was refueled with #2 Diesel fuel containing 0.21 wt. % sulfur. This fuel was used throughout the sulfate testing.

2. The vehicle was driven over one LA-4 cycle with the test fuel in preparation for the test series.

3. The following sequence of test cycles was used to measure sulfate emissions.

a) Cold start '75 FTP
b) Two hot start sulfate cycles
c) One EPA Highway Driving Cycle
d) Two hot start sulfate cycles.

This sequence was run on two consecutive days.

4. The barium chloranilate procedure was used to determine the concentration of sulfates in the exhaust.

TEST VEHICLE DESCRIPTION

Chassis model year/make - 1975 VW Rabbit Sedan
Emission control system - Engine Modifications

Engine

type	4 stroke, Diesel, I-4, ohc, indirect injection
bore x stroke	3.012 x 3.149 in./76.5 x 80.0 mm
displacement	90 cu in./1475 cc
compression ratio	23.5:1
maximum power @ rpm	48 net hp @ 5000 rpm/36 kW @ 5000 rpm
fuel metering	Bosch fuel injection, mechanical
fuel requirement	#2 Diesel

Drive Train

transmission type	4 speed manual
final drive ratio	4.22:1

Chassis

type	unibody, transversely-mounted front engine, front wheel drive
tire size	155 R x 13
curb weight	1950 lbs/885 kg
inertia weight	2250 lbs
passenger capacity	4
durability accumulated on system	4500 mi./7200 km